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A Comparison of Satellite-Observed Sea-Surface Temperatures With Ground Truth in the Indian Ocean

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A COMPARISON OF SATELLITE-OBSERVED SEA-SURFACE TEMPERATURES WITH GROUND TRUTH IN THE INDIAN OCEAN

Ants Leetmaa
Matthew Cestari

Daily worldwide sea-surface temperature maps are produced by the National Environmental Satellite Service. For the first half of 1975, sea-surface temperatures recorded on these maps were compared with concurrent ship observations in the Indian Ocean. Additional comparisons were made with historical data. These show systematic differences between the satellite and sea-surface observations. The satellite-derived temperatures appear to be too low along the equator and along the East African coast in the vicinity of the equator. Furthermore, in April, May, and June the areas off the equator (and not along the coast) appear to have temperatures that are too high. Although the mean differences are not large (1°-2°C), the fact that the errors vary in time and space made it difficult to apply the satellite data for oceanographic interpretations.

1. INTRODUCTION

Numerical experimentation has shown that the tropics are an important area for interactions and feedbacks between the ocean and the atmosphere. From present planning, it is clear that during the First GARP Global Experiment (FGGE) equatorial regions will receive special attention in the ocean as well as in the atmosphere. The Indian Ocean, because of the monsoons, will also have a special observing period during FGGE, the Monsoon Experiment (MONEX).

Because of the importance of equatorial regions to climatic studies, and because FGGE will provide relatively complete meteorological coverage, a group of oceanographers has started planning an Indian Ocean Experiment (INDEX). The primary goal of INDEX will be to study the transient reponse of a low latitude ocean to a strong regular forcing by the atmosphere. Pilot experiments, whose results will aid in the design of the final experiment, are now taking place. Sea-surface temperature maps from satellite data could be a valuable tool to study the onset of the Somali Current, upwelling along the Arabian coast, and heat budgets in the Arabian Sea. At the present time such maps are available from the National Environmental Satellite Service. However, as with every new product or technique, they have to be examined carefully to ascertain their limits of accuracy and applicability. This study reports on a number of intercomparisons between the satellite-observed sea-surface temperatures and "ground truth" in the Indian Ocean during the first half of 1975. The results suggest that more work has to be done before reliable sea-surface temperatures can be obtained from satellites.

2. THE SATELLITE-OBSERVED SEA-SURFACE TEMPERATURE MAPS

The National Environmental Satellite Service provides daily worldwide satellite sea-surface temperature (SSST) maps. This product is known as the Global Sea-Surface Temperature Computation (GOSSTCOMP). One form of this is an uncontoured computer printout with sea-surface temperature values for each one-half degree of latitude and longitude. With each numerical value for temperature is a code that indicates the estimated reliability of the data. If the code is "+4", then the last reading had been taken four days before the date of the map, etc. If the number of days exceeds nine, the code space is blank, and the temperature value given is from historical data. If data are available for the day of the map, a letter appears in the code space. An "+A" indicates that the temperature listed is an average of five readings. A "+B" indicates an average of five to eight values and so on up to "+H" which indicates that over 25 values were averaged. The better maps in our analysis had mostly D's through H's associated with the temperature readings.

For this study, the daily map with the highest code letter was selected to represent an entire week. One day was chosen to be representative of a whole week because changes from day to day were observed to be small, and weekly representations were more readily compared than daily maps. They start with the week of January 3-9 and end with June 1-7, 1975. Each map selected was contoured in the area of the Indian Ocean off the coast of Africa from 6°S to 15°N and 35°W to 65°E in latitude and longitude. From the collection of maps, one was selected from the early portion of each month to illustrate any monthly differences (Figs. 1-3).

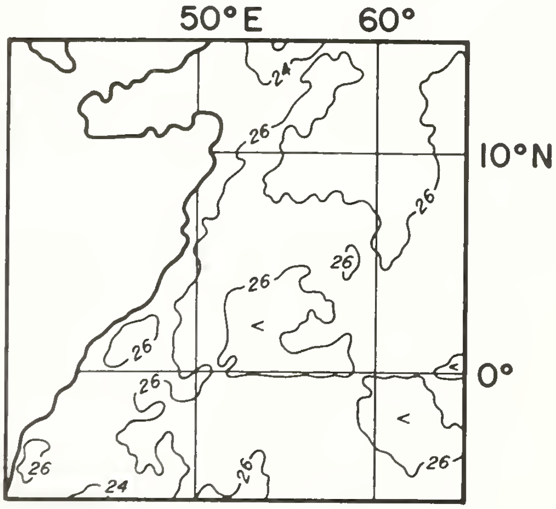


Figure 1. Satellite sea-surface temperature data for January 1975.

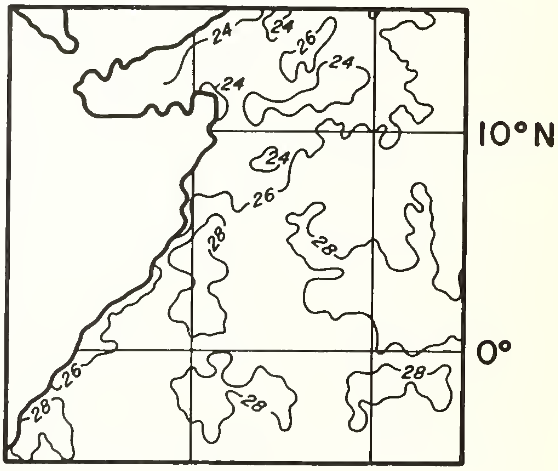


Figure 2. Satellite sea-surface temperature data for February 1975.

3. SEA-SURFACE TEMPERATURE VARIATIONS ACCORDING TO SATELLITE DATA

The seasonal variations of sea-surface temperatures in the Indian Ocean is strongly related to the NE and SW monsoons, the transition periods between them, and the ocean current systems established by the winds. The features observed on the maps must be interpreted in the context of these phenomena. Figure 1 shows that there was not a wide range of temperatures in January. Most of the readings were either slightly greater or less than 26°C. On either side of the equator the temperatures are somewhat warmer than at the equator. During February (fig. 2), the sea surface immediately north and south of the equator warms, while temperatures at the equator remain cool, as in January. North of approximately 8°N the temperatures begin to decline with areas containing temperatures lower than 24°C. This is colder than in January. In March (fig 3) the same pattern persists, but a warming trend is evident. The area of the equator continues to remain cool, and the areas immediately north and south of the equator (5°S-8°N) are warmer. Larger areas of 28°C and higher temperatures are visible, with 30°C temperatures reported for some locations. Temperatures for April (fig. 4) show an increased warming trend, with many areas containing temperatures of 30°C and higher.

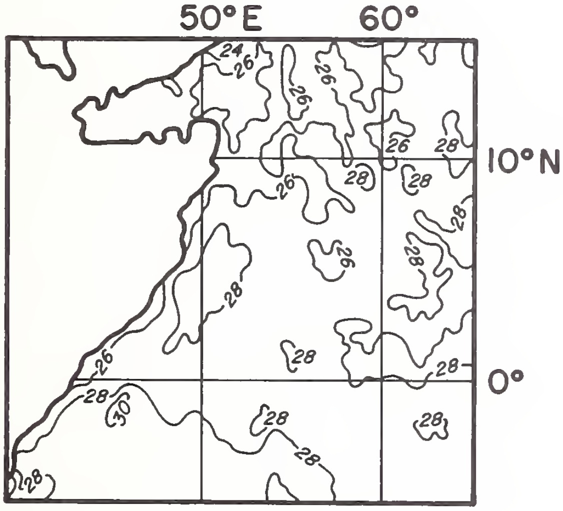


Figure 3. Satellite sea-surface temperature data for March 1975.

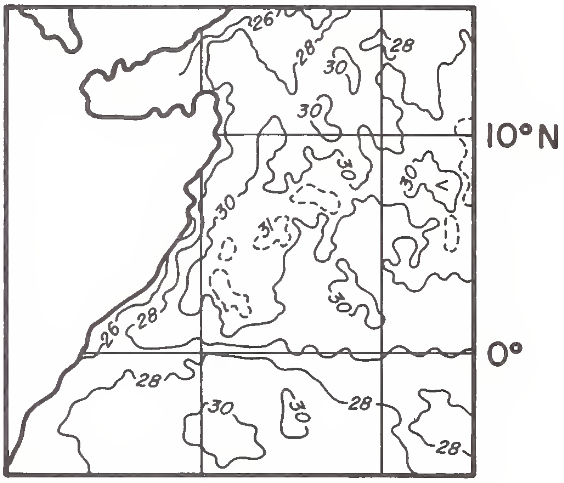


Figure 4. Satellite sea-surface temperature data for April 1975.

Temperatures in the area of the equator, as noted in all previous months, remain between 26°C and 28°C. Areas immediately north and south of the equator have become considerably warmer. In the north there are isolated areas with temperatures higher than 31°C. The warmest month from January to June, 1975, is May (fig. 5). Again the area at the equator remains cool. Large areas of 30°C and higher temperatures are visible north and south of the equator. The north exhibits a slight cooling trend in June (fig. 6). The equatorial band remains cool, and areas to the north and south become cooler. Fewer and smaller areas of 30°C and higher temperatures are still present, and the major portion of the entire region contains temperatures of 28°C or slightly higher. The areas of 30°C and higher temperatures seem to have moved toward the north and south, away from the area immediately north and south of the equator. In all months, temperatures along the East African coast were cooler than those offshore.

On first glance the seasonal variation in the sea-surface temperature pattern as seen from these maps appears to be reasonable. The transition period between the northeast and the southwest monsoon occurs during March. April, and through the middle of May. A major factor in the heat budget of the surface layers is evaporation, which is proportional to wind speed. During the transition, the evaporation decreases and the sea-surface temperature increases. The cooler coastal areas could be related to upwelling or to north-south transport of cooler water by the Somali Current along the coast. A feature that is anomalous, however, is the cool band of water along the equator. In the Pacific and Atlantic Oceans, such a cool band is indicative of equatorial upwelling. However, in the Indian Ocean the winds are not favorable for upwelling, and this feature is rarely present. To examine the validity of this indication and others in more detail, a comparison was made of these satellite data with data from a number of other sources.

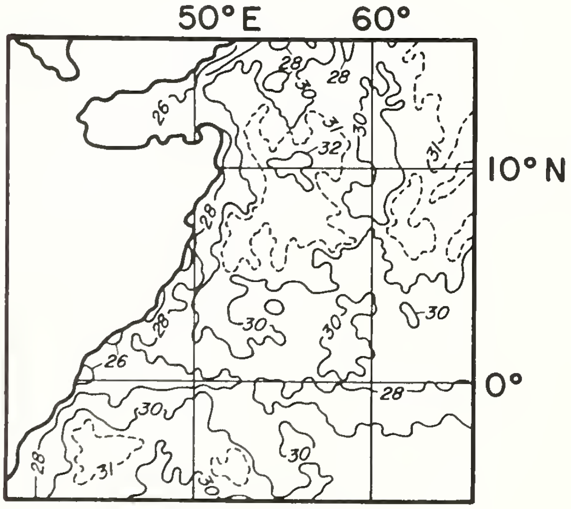


Figure 5. Satellite sea-surface temperature data for May 1975.

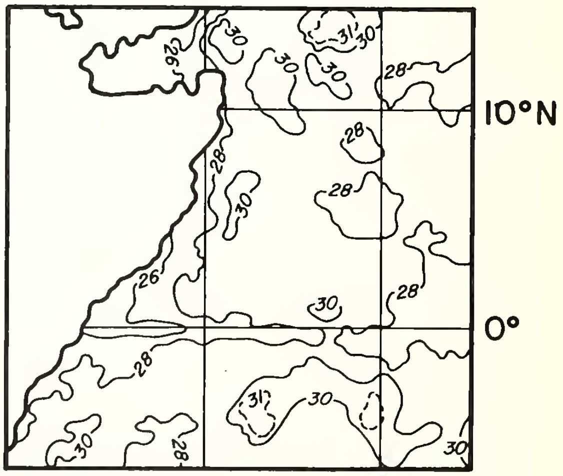


Figure 6. Satellite sea-surface temperature data for June 1975.

4. COMPARISON OF SATELLITE DATA WITH SHIP REPORTS

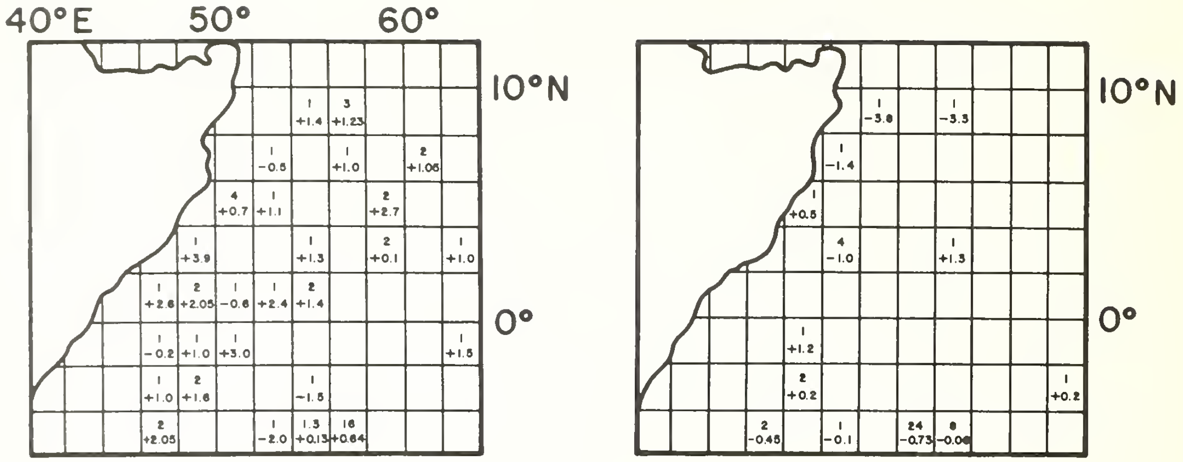
We can compare the satellite data with actual ship observations obtained at the same time in the same area. For February through May 1975 data are available from a chartered research vessel, *La Curieuse*, in the vicinity of the equator. Bucket thermometer readings (estimated accuracy ±0.2°C) were taken periodically along 55°40'E from 3°S to 2°N. The National Weather Service also provides information on air temperature, dew point, and sea surface temperature at ship positions through its twice-daily surface-weather maps.

There were 106 cases in which bucket thermometer readings from *La Curieuse* could be compared with data from the satellite. The mean difference for the whole data set was +0.4°C. Temperatures recorded from the ships were, on the average, higher. The standard deviation was 0.9°C. This indicates that the scatter was quite large. The mean difference actually is rather small. However, if the data are studied in more detail, it becomes clear that there are obvious trends. The satellite temperature data for the equator are always lower than the surface observations and the difference becomes greater as time goes on. For example, for all intercomparisons (32) in the region from 0.5°S to 0.5°N the mean difference is +0.9°C. The standard deviation is 0.7°C. Clearly the equator is systematically colder in the satellite data. This conclusion supports our previous speculations.

The satellite data were also compared with merchant ship reports. Unfortunately, there is a very limited amount of ship data available in real time. Also, frequently only the air temperatures are available rather than the sea-surface temperatures. In the tropics this is not a serious problem because the differences between these are usually small. Thus, to maximize the data set, the ship reports were compared three ways. First the Satellite Sea Surface Temperatures (SSSTs) were compared with the reported air temperatures. The SSSTs were then compared with the sea-surface temperatures, and finally with air and sea temperatures that were within one degree of each other. Approximately 270 ship reports were available in the period from January to June 1975.

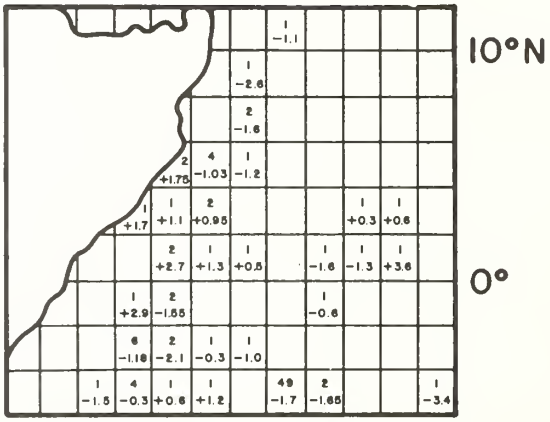
The difference between air temperature from ship reports and satellite sea-surface temperature was determined from three 2-month groups. For January-February, the mean difference was +0.85. For March-April it was -0.59, and for May-June it was -0.97. This indicates that the satellite temperatures are lower than actual temperature measurements for January and February, but higher than actual for March-April and May-June. These differences also appear to have a geographic dependence. Figure 7 shows the geographical distribution of these differences. For May-June the satellite reads low in the vicinity of the equator and along the Somali coast, and high elsewhere. March-April shows the same trend. In January-February the satellite reads systematically low almost everywhere.

The difference between sea-surface temperatures from merchant vessels and SSST was investigated for only May-June because not enough data were available for other months. The geographic distribution of the differences is shown in figure 8. Again the satellite appears to read low in the vicinity of the coast and the equator and high elsewhere.



January-February

March-April



May-June

Figure 7. Geographic distribution of differences between air temperatures and satellite sea-surface temperatures. The upper number in each square indicates the number of comparisons.

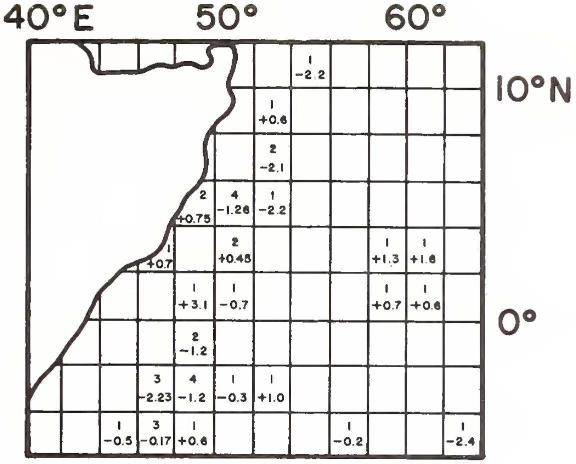


Figure 8. Geographic distribution of differences between sea-surface temperatures from merchant ships and satellite sea-surface temperatures for May-June 1975.

For a final intercomparison, we computed the monthly mean (SSST) for April, May and June, 1975 for the areas: REGION I - 12°-13°N, 54°-56°E; REGION II - 11°-12°N, 54°-55°E; REGION III - 10°-11°N, 53°-55°E (fig. 9). We compared these with the 21-year mean temperatures in these regions as derived from all ship reports on file at the National Climatic Center. These were computed by Fieux and Stommel (1975). The results are presented in Table 1.

It should be noted that the satellite data, except for one comparison always give higher temperatures than the historical data do in this region. In April and June the satellite temperatures are nearly always two standard deviations away from the historical temperatures.

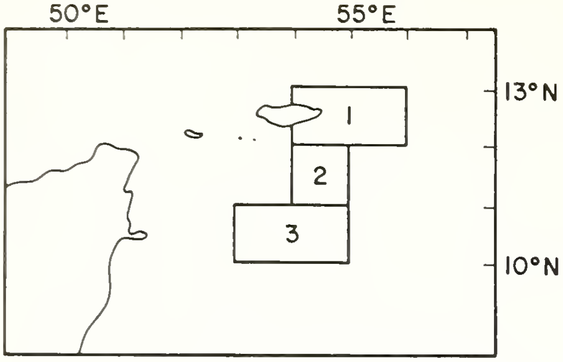


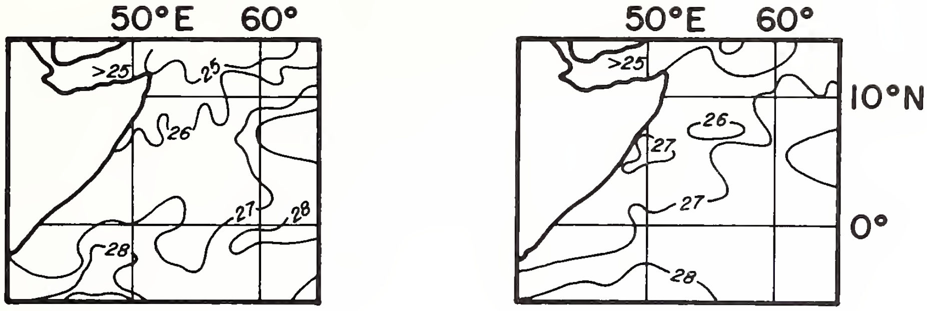
Figure 9. Regions for which comparisons were made between satellite sea-surface temperature data and historical ship data.

Table 1. Comparison of Average SSST's with Historical Ship Data.

	SSST	SHIPS	SSST	SHIPS	SSST	SHIPS	
	April		May		June		
REGION I	28.49	28.52	29.64	29.51	29.32	27.90	Mean Temp.
		0.48		0.66		0.86	Standard Deviation
REGION II	29.25	28.38	30.34	29.50	29.74	27.17	Mean Temp.
		0.60		0.78		0.90	Standard Deviation
REGION III	29.93	28.84	30.82	29.43	29.49	26.65	Mean Temp.
		0.56		1.06		1.20	Standard Deviation

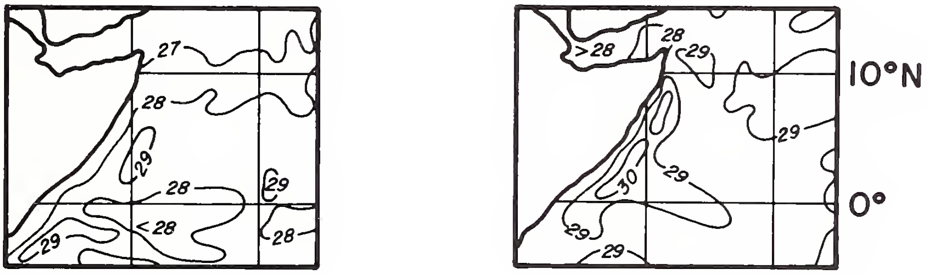
5. COMPARISON OF SATELLITE DATA WITH 1963 SURFACE OBSERVATIONS

From the International Indian Ocean Expedition, data are available on sea-surface temperature for 1963 (Wyrtki, 1973). These were accumulated from surface observations from ships. Maps for January through June 1963 (see fig. 10) may be compared with satellite temperature maps from 1975. One obvious difference is that in January-June, 1963, there was no equatorial temperature minimum. Also in the 1963 data, there is no indication that along the coast sea-surface temperatures are lower for January-April as they are in the satellite data. Another difference between the two data sets is that the International Indian Ocean Expedition maps for April and May contain



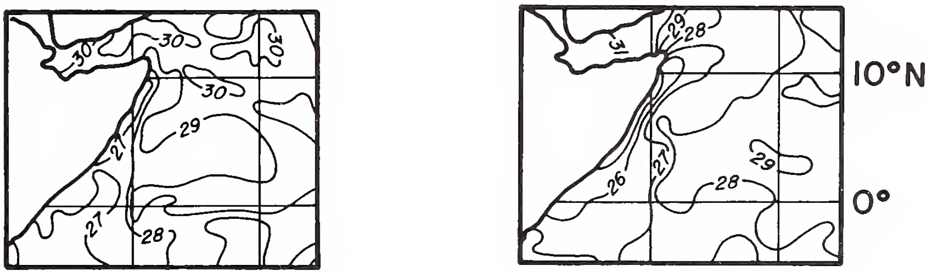
January

February



March

April



May

June

Figure 10. Sea-surface temperature data for 1963 obtained from the International Indian Ocean Expedition.

temperatures of 30°C and slightly above as maximum temperatures for the area being studied, while the satellite maps contain areas with temperatures above 31°C for April and above 32°C for May. The maximum temperatures are therefore higher in the satellite readings than in the 1963 International Indian Ocean Expedition data. This, of course, might be related to year-to-year variations.

The final major difference between 1963 and 1975 data is the north-south temperature gradient for May. The satellite temperatures range from 27°C at the equator to greater than 32°C at about 10°N along 55°E, while the International Indian Ocean Expedition data range from 29°C to between 30°C and 31°C in the same area. Clearly the satellite temperature data have a wider range. Satellite-measured temperatures are higher in warm areas and lower in cool ones than temperatures measured at sea-surface.

6. SUMMARY

It is difficult to obtain reliable sea-surface temperature data for the Indian Ocean. Potentially, satellite IR data could satisfy this need. However, the quality of these data has to be assessed before extensive use can be made of them. Since ground truth is difficult to obtain in this region, we tried to evaluate the SSST's by comparing them with data from a number of independent sources. In each case, the intercomparisons showed serious discrepancies between the satellite data and the ground truth. Although any one result might be suspect, a clear trend emerged from the analyses. The SSST's appear to be too low along the equator and along the East African coast in the vicinity of the equator for the time period examined. Furthermore, in April, May, and June in the areas off the equator and not along the coast, they appear to be too high.

On the basis of this study, one would have to conclude that the SSST's, at least for the Indian Ocean, are suspect. The errors appear to vary geographically in time and more work must be done if SSST's are to be of great usefulness to oceanography. Meteorologically, improved SSST's are very important because during FGGE, SSST's will be used in the numerical models. An enhanced north-south temperature gradient in the models will probably create unrealistic atmospheric circulation patterns in the tropics.

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